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Suitability analysis for implementing a renewable energy powered water purification system

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Abstract

In the developing world, people not only lack access of grid electricity, but also safe drinking water. There are many causes of waterborne diseases due to drinking unsafe water use from surface water sources. Under these circumstances, renewable energy based water purification can be an appropriate solution. Applying Geographical Information System (GIS) technique for implementing decentralized renewable energy based system to provide safe drinking water to vulnerable communities can be a useful tool to policy makers and administrative authorities in finding sustainable options. This paper presents a concept of using GIS bound renewable energy based water purification system. Using GIS as a tool, suitable areas can be identified for using such a system, and this can also be used to estimate water demand, energy demand and the nature of the water purification system at household and community level. The proposed concept was applied in Pathumthani province, Thailand as a study area. The renewable energy potential from PV, water demand, energy demand and the sensitivity to the system identification due to the influence of various parameters have been estimated and presented.

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Keywords: Geographic Information System (GIS); Photovoltaic; Renewable energy; Water purification system; Sustainable development

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1. Introduction

Lack of hygienic drinking water and lack of basic sanitation is the major cause for many water related diseases. There are many causes of waterborne diseases due to drinking unsafe water use from surface water sources. Under these circumstances, a renewable energy based water treatment system could be useful in areas that lack both grid electricity and hygienic drinking water facilities and could be a good stand alone solution for this problem [1]. This type of system may have a dual benefit wherein hygienic drinking water will improve the quality of life and the use of renewable energy will help in reducing the use of fossil fuels [2, 3].

Alternatively, there are many technologies that are available to combine renewable energy technology with a water purification system, such as PV powered reverse osmosis (PV-RO), wind powered reverse osmosis (Wind-RO), PV powered UV disinfections and solar photo-catalysis, in which, sunlight and a reusable reaction medium such as Titanium dioxide (TiO_2) is used to remove toxins from ground water [4, 5]. Another possible combination can be PV powered pumping with ultra filtration membrane technology (UF) [6, 7]. This type of system could be simple, compact and easy to operate. Fig. 1 presents a schematic of PV pumping and a membrane based water purification system. This type of system may consist of a UF membrane, a PV array, a PV pump, and a water storage system. This kind of sustainable technology can be used where surface water is available but the water is not safe for drinking.

Considering the need to provide safe drinking water to the households and communities that do not have this access, the following issues need to be resolved by government administrative authorities:

- How much water (not necessarily safe) is available in the vicinity of the population to be supplied – this requires mapping of the households and communities, knowledge of the streams and water bodies that can be the source of water,
- How to bring this water to the population (the energy resource available at the location of interest, and the technologies required – electricity by grid or through de-centralized electricity supply systems such as PV, wind, diesel, etc), and
- Information on the quality of water available for this purpose, and what are the options available to treat the water to make it safe for drinking.

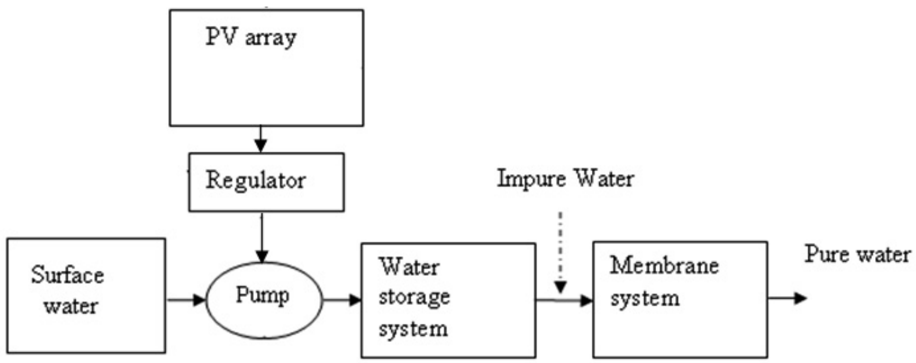

Fig. 1. Schematic diagram of solar photovoltaic based water purification system

The constraints in carrying out this task would depend on many factors: distances to transport the water from the source to the households and communities – what is the threshold distance, availability of roads, access to electricity grid, and water treatment systems. These constraints can be modeled and taken into consideration by the use of Geographic Information System (GIS) that plays an important role in natural resources and environmental management as well as economic and social development [8]. GIS can be used in determining the suitable locations of renewable energy based water purification systems. Utilization of GIS with renewable energy projects can help policy makers and renewable energy companies allocate their resources efficiently and improve the life of people in affected areas of developing countries [9].

This paper presents the usefulness of applying GIS techniques for the application of decentralized renewable energy based water purification system using Pathumthani province, Thailand as a study area. For this district, based on available digitized data, the study first identified the households that do not have access to safe drinking water, and for these households and communities, the water demand and the energy demand to pump the water using a renewable energy based system was estimated. A simple membrane based water treatment system was considered in order to propose a methodology for addressing the global issue of safe drinking water and promotion of renewable energy technologies. The concept and methodology proposed are shown by the use of a case study expected to be of use to district authorities, government organizations and all others involved in providing safe drinking water to the communities.

2. Study Area and Data Requirement

Muang Pathumthani is one of the districts of Pathumthani province in central Thailand. It is situated on the Chao Phraya river basin. Muang Pathumthani has 13 tambons with a total population of 129,649. Out of this 24,547 live in the municipal area and 105,102 live in non-municipal areas. Fig. 2 presents the administrative map of Muang Pathumthani.

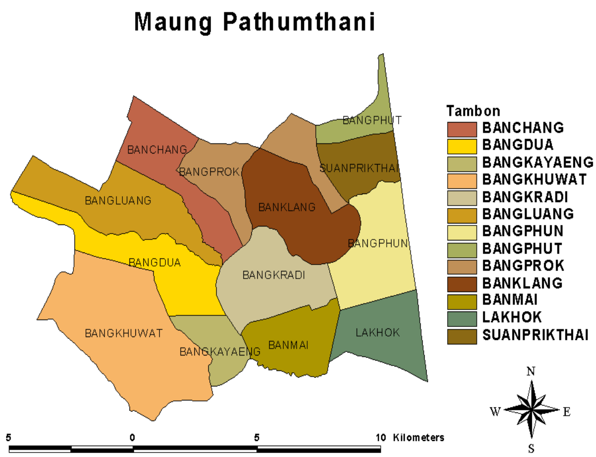

Fig. 2. Administrative map of Maung Pathumthani

The input data that is used for the GIS study includes an administrative map of Muang Pathumthani, data regarding households without access to regular water supply, the existing road and stream network, current grid electricity network and solar radiation data. However, due to non-availability of recent digitized data, some ten year old data was used to carry out the study. Table 1 summarizes the input data used in the study.

Table 1. Detailed input data used for the study

Theme	Description
Administrative area map	- Tambon code - Name of the Tambon - Shape area
Road network map	Road ID, Length of road network Road type: 1. Two lanes wide hard surface road 2. Two lanes wide light surface road 3. Loose surface road 4. Cart track
Stream network map	Stream ID, Length of stream Stream type: 1. Major river or canal 2. Perennial stream
Population data	- Population data - Household data
Grid electricity network map	Grid ID, Length of grid line Grid electricity type: 22 kV line
Household data	- Household with water supply data - Household without water supply
Solar radiation data	- Monthly solar radiation - Average yearly solar radiation

3. Methodology

3.1. Identification of areas for consideration

The primary goal is to identify the suitable areas, which are really far i.e. areas far from the grid, far from road network and areas having low access to regular water supply. However, these areas should be near to natural water sources such as streams or canals for ease of access for water purification system. The GIS ArcView tool was used to identify suitable areas in Muang Pathumthani. Input data used for identifying suitable areas were the administrative boundary map, grid electricity, road and stream network map and household data with less access to regular water supply service. To identify the suitable areas, the following criteria were used:

- 1 km away from the grid line
- 0.5 km away from a road network
- 0.2 km nearer to a stream
- Areas having less access to regular water supply service

Using geo-process wizards in ArcView software, 1 km buffers were created around the grid electricity line. The buffer map was clipped from the administrative boundary map to obtain the areas that lie outside the buffer area. Similarly, 0.5 km and 0.2 km buffers were created for the road network and streams, and thus the areas far from the road buffer and nearer to the stream buffer were selected. Finally, overlaying this theme with a household map (for households having low access to regular water supply), suitable areas were selected based on areas that have less access to a regular water supply. Fig. 3 shows a flowchart used for identifying the suitable areas.

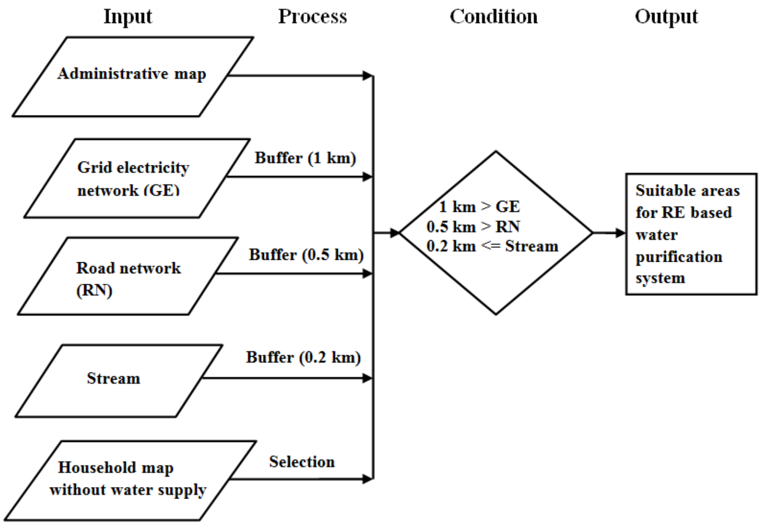

Fig. 3. Methodology for identifying suitable locations for renewable energy based water purification systems

3.2. Estimation of water and energy demand

To estimate the water demand for limited domestic use purposes, the energy demand for a water treatment system, size of the water treatment system, and the availability of solar energy under limited conditions, the following methodology was used. The minimum water demand per person for limited domestic use can be considered as 25 liter/person/day [10]. The average household size of Pathumthani province is 4 persons for non-municipal areas [11]. Using equation (1) the minimum water demand for the suitable area was derived.

$$WD = HH_{nw} \times P_{hh} \times Min_{wd} \tag{1}$$

where, WD is the drinking water demand (liter/day)

HH_{nw} is the number of household without water supply service (household)

P_{hh} is average persons per household (person/household)

Min_{wd} is minimum water demand per person for limited domestic use (liter/person/day)

Table 2 presents detailed data used for the estimation process of a water treatment system requirement and energy demand for the household and community level. The requirement of a water treatment system and energy demand for the system was categorized into household level and at community level. It is assumed that a minimum of one pump will be required to run the water purification system and the energy required to run the pump is the energy demand for the system. However, the pump size may vary at household level and the community level. The energy demand for the water treatment system was estimated as equation (2).

$$ED = P \times T \times WTS \tag{2}$$

where, ED is the energy demand (Wh)
P is the pump rated capacity (W)
T is the pump operation time (h)
WTS is the number of water treatment systems (household/community)

Table 2. Detailed data used in the estimation process of water treatment system requirement and energy demand for household and community level

Parameter	Household level	Community level
Number of water treatment systems	1 system for each household	1 system for each community (1 community = 20 households)
Water demand per household	100 liter/day	2000 liter/day
Maximum capacity (Water treatment system)	8 liter/hour	1000 liter/hour
Maximum capacity (PV pump)	0.025 m^3/hour, 40 W Pump will require 4 hours to pump 100 liter/day at average flow rate of 0.4 liter/min	0.025 m^3/hour, 80 W Pump will require 8 hours to pump 2000 liter/day at average flow rate of 4.2 liter/min

3.3. Estimation of annual solar energy available

The suitable area map and monthly mean global solar radiation data (horizontal and tilted) was used as input data for estimation of renewable energy [12-14]. Using equation (3) the annual electrical output from a PV panel can be calculated.

$$E = 365 \times P_{pv} \times \eta \times A \times G \tag{3}$$

where, E is the annual electrical output from PV panel
P_{pv} is the peak power of PV system (W)
η is the system efficiency
A is the area of PV module (m^2)
G is the mean daily global solar radiation on panel

The electrical energy output from PV was estimated under:

- 75 W_p TPS 105 polycrystalline solar panels having an area of 0.63 m^2 that could be installed in each household (Households far from grid electricity and having less access to regular water supply service).
- Monthly mean global radiation of horizontal and 15° tilted panel was considered for estimating the solar radiation incident on the PV panel.

4. Results and Analysis

4.1. Identification of suitable areas for PV based water pumping system installation

The areas that were identified as suitable for a renewable energy based water treatment system are presented in Fig. 4. Seven suitable areas were found from 13 tambons, which are located far from the grid (> 1 km) and road network (> 0.5 km) and have less access to regular water supply but easy access to a natural water source (< 0.2 km). These seven suitable sites are in the tambons of Bangluang, Bangdua, Bangkhuwat, Bangkradi, Bangphut, Suanprikthai and Bangphun. Table 3 presents the detailed household data for these locations.

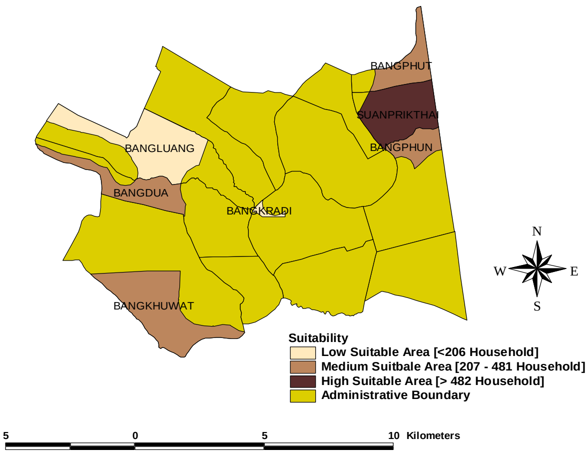

Fig. 4. Suitable areas for renewable energy based water purification systems

Table 3. Household data for the selected sites

Tambon	Number of households with regular water supply	Total number of households	Number of households in selected sites with less access to water supply
Bangphut	215	814	481
Suanprikthai	0	1069	1011
Bangluang	49	406	206
Bangphun	289	2954	470
Bangdua	610	1445	291
Bangkradi	73	1084	23
Bangkhuwat	284	1192	299

4.2. Drinking water demand and water treatment system requirement

The water consumption was estimated at both household and community level as discussed in the methodology. As water demands depend on household density, total water demand will be the same for both household and community levels. Fig. 5 presents the water demand for limited domestic uses.

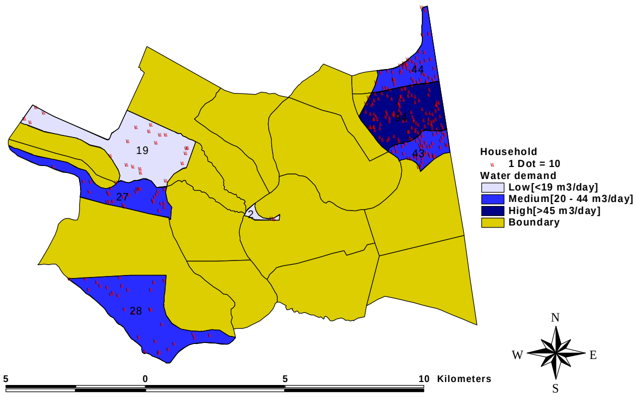

Fig. 5. Water demand for limited domestic uses

The estimation as presented in Table 4 shows that the selected site in Suanprikthai tambon has the highest water demand of 94 m^3/day whereas Bangkradi has the lowest water demand of 2 m^3/day.

Table 4. Total water demand for the selected areas

Tambon	Area of selected sites (m^2)	Number of households in selected sites	Number of communities in selected sites	Drinking water demand (m^3/day)
Bangphut	2,810,148	481	24	44
Suanprikthai	5,645,717	1011	51	94
Bangluang	7,804,418	206	10	19
Bangphun	1,932,968	470	24	43
Bangdua	4,012,426	291	15	27
Bangkradi	260,374	23	1	2
Bangkhuwat	7,969,706	299	15	28

4.3. Water treatment system requirement and energy demand for the system

As mentioned in the methodology, commercially available ultra filtration models DUFO-50 (Household level) and S-430 (Community level) were considered for water treatment systems in this study, having a capacity of 8 L/hour and 1000 L/hour respectively. Fig. 6 and 7 present the water treatment system requirement map for household and community levels. The estimation results show that Suanprikthai will require 1011 systems at the household level and 51 systems at the community level, which is the highest. Similarly, the selected sites in Bangphut and Bangphun will require the second highest number of water treatment systems after Suanprikthai. On the other hand, Bangkradi requires the lowest number of water treatment systems on both the household and community levels as it has more access to regular water supply than other selected areas.

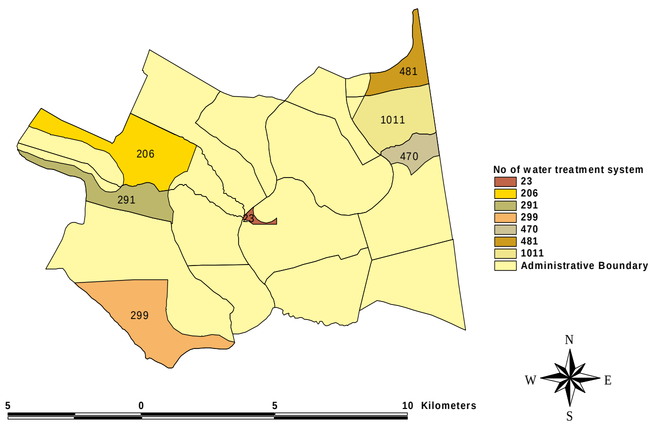

Fig. 6. Water treatment system requirement map for household level

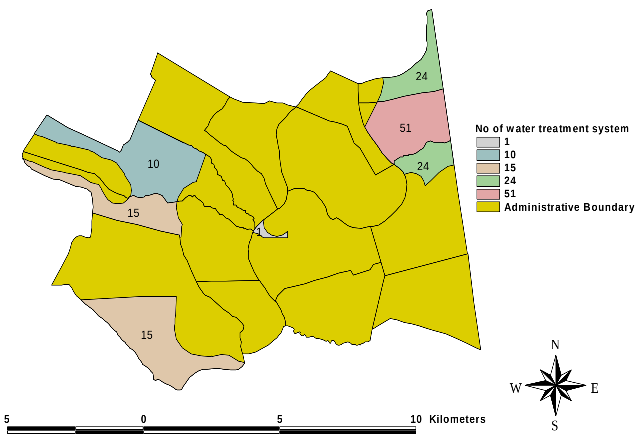

Fig. 7. Water treatment system requirement map for community level

4.4. Energy demand for water treatment systems

The annual energy demand was calculated for the water treatment systems as mentioned in the methodology and the areas were categorized as low, medium and high-energy demand areas based on the energy consumed by the water treatment systems. Table 5 presents the annual energy demand for household and community level water treatment systems.

Table 5. Annual energy demand from water treatment systems in household and community levels

Tambon	Number of systems in household level	Number of systems in community level	Annual energy demand in household level (kWh/yr)	Annual energy demand in community level (kWh/yr)
Bangphut	481	24	28,090	5606
Suanprikthai	1011	51	59,042	11,914
Bangluang	206	10	12,030	2336
Bangphun	470	24	27,448	5606
Bangdua	291	15	16,994	3504
Bangkradi	23	1	1343	234
Bangkhuwat	299	15	17,462	3504

Fig. 8 presents the annual energy demand map for water treatment systems at the household level. Bangluang and Bangkradi were classified as low energy demand areas as their energy consumption was lower than 12,031 kWh/yr at the household level from water treatment systems. Similarly, Bangphut, Bangphun, Bangdua and Bangkhuwat come under the medium energy consumption zone with energy demand for the water treatment systems being within the range of 12,031 – 28,090 kWh/yr. Suanprikthai was classified as a high energy demand area, as it required 1011 water treatment systems at the household level.

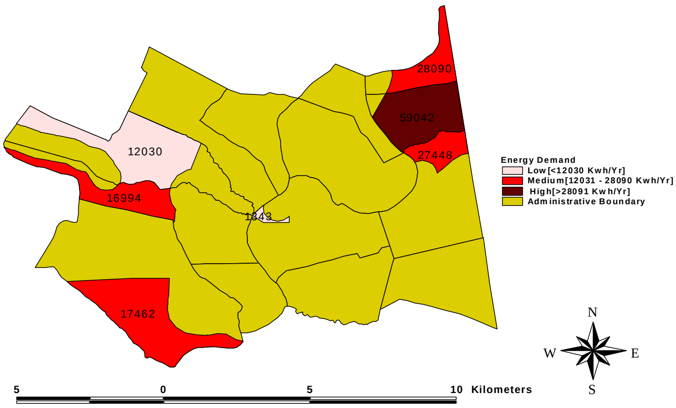

Fig. 8. Annual energy demand from water treatment systems at the household level

Similarly, for the community level as shown in Fig. 9, Bangluang and Bangkradi were classified as low energy demand areas with energy demands being less than 2337 kWh/yr. Bangphut, Bangphun, Bangdua and Bangkhuwat will require between 15 and 24 water treatment systems and are medium energy consumption zones. Their annual energy demand for the water treatment systems was within the range 3504 – 5606 kWh/yr. Suanprikthai was classified as a high energy demand zone, as it required 11,914 kWh/yr. It is seen that community level water treatment systems require less energy than household level systems and will save more energy compared to household level systems.

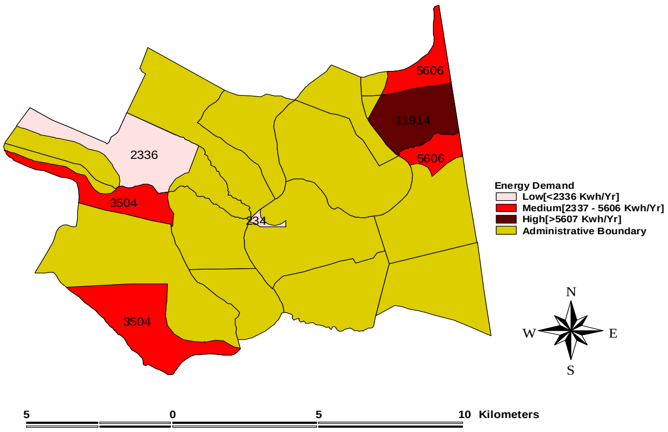

Fig. 9. Annual energy demand from water treatment systems at the community level

4.5. Electrical energy output from a 75 W_p PV panel

The theoretical electrical output from a 75W_p PV panel was estimated under limited conditions using equation (3) as mentioned in the methodology and households that do not have access to regular water supplies were considered for panel installations. This electrical output from the PV panel was estimated for horizontal and tilted panels (15°) and Fig. 10 and 11 present the annual PV output from 75W_p systems.

The estimated annual electrical output from a 75 W_p PV panel was less than 12,790 kWh/yr for selected sites under Bangluang and Bangkradi. Similarly, estimated annual electrical output from 75 W_p varies between 18,067 – 29,864 kWh/yr for areas under Bangphut, Bangphun, Bangdua and Bangkhuwat. The selected site of Suanprikthai yields an annual electrical supply of 62,769 kWh/yr from the PV panels, which is the highest among all selected areas.

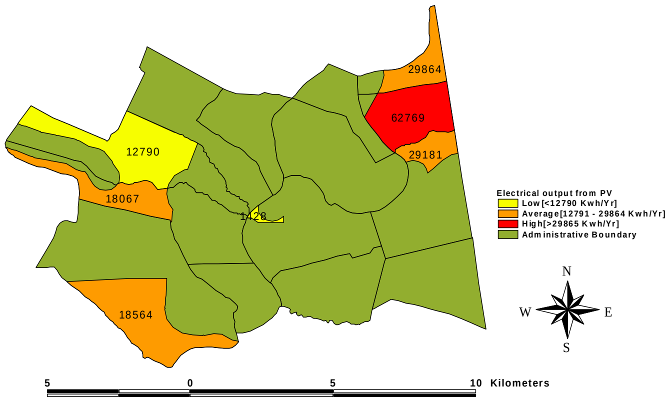

Fig. 10. Annual electrical output from 75 W_p PV panel (Horizontal)

The use of tilted PV panels will increase the annual electrical output to 13,056 kWh/yr and 1458 kWh/yr for the selected areas of Bangluang and Bangkradi respectively as the radiation falling on the tilted panels will be more compared to that falling on horizontal panels. Fig. 11 presents the PV output from a tilted panel for the selected sites. Similar to a horizontal inclination, this output varies between 18,444 – 30,486 kWh/yr for the areas under Bangphut, Bangphun, Bangdua and Bangkhuwat. The use of tilted PV panels will increase the annual electrical output to 64,077 kWh/yr in the case of Suanprikthai. This shows that there is sufficient renewable energy available from PV to meet the energy demand from the water treatment systems.

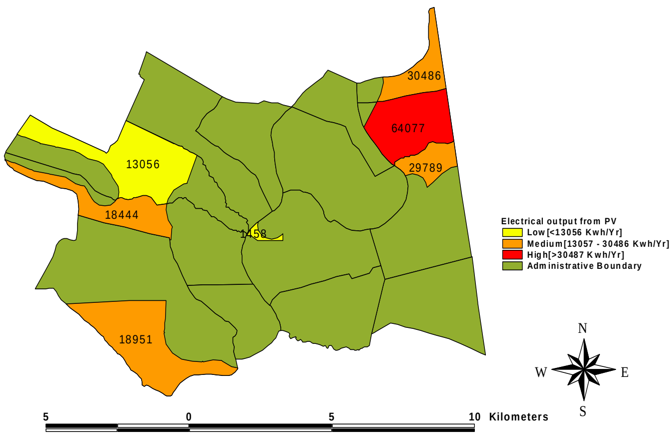

Fig. 11. Annual electrical output from 75 W_p PV panel (Tilted 15°)

5. Conclusion

As the proposed model and the results are based on GIS, it is easy for the planners and project developers to visualize the results. The output of the proposed model would help the project designers to select suitable sites for implementation of renewable energy based water purification systems. It can identify not only suitable locations for such systems but also provide additional information such as water demand, energy demand, and the requirement for water purification systems for those areas. The results also showed that the renewable energy potential or annual electricity demand that can be produced from PV panels can also be estimated. This type of GIS-bound system presents wider scenarios such as, which type of system installation will result in greater energy savings, and whether there is sufficient renewable energy available to meet the demand.

The reliability of the modeling results are crucially dependent on the quality of the input data in terms of spatial resolution, accuracy, actuality and other typical GIS data parameters. In this paper, the possible renewable resource of solar photovoltaic power is considered to meet the arising future energy demands in the selected areas. The information can be further complemented by considering the financial aspects taking note of the system costs, maintenance costs, operation costs, etc. Moreover, depending on the quality of water available, various types of water purification systems can be incorporated in the analysis (technical and financial), and this could help the decision makers in the selection of sites and the systems. However, the use of recent data may give more accurate results when compared to this study. The sensitivity analyses results showed that a change in important parameters may not only influence the results but also help in making more accurate decisions. This type of study can be further extended to other areas where such systems can be useful.

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